Memoranda
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Protein and energy requirements: a joint FAO/WHO Memorandum *

Since the publication in 1973 of the report of a Joint FAO/WHO Ad Hoc *Expert Committee on protein and energy requirements, some investigations have indicated that the safe levels of protein intake recommended in that report may be too low. This Memorandum reviews the current situation and makes further recommendations where necessary.*

Current recommendations by the Food and Agriculture Organization of the United Nations and the World Health Organization on protein and energy requirements are based on two reports. The first (*1*) is that of a Joint FAO/WHO *Ad Hoc* Expert Committee on Energy and Protein Requirements, which met in 1971 (referred to as the 1971 Committee) and which reported in 1973 (referred to as the 1973 report). The second (*2*) is the report of a joint FAO/WHO informal gathering of experts, which met and reported in 1975 (referred to as the 1975 report). The aim of the latter meeting was to provide guidance on some matters that had not been adequately considered in the 1973 report, particularly the digestibility of protein, the significance of the protein/energy ratio, and the requirements for people who are underweight. The purpose of the present report is twofold: first, to clarify the basis on which some of the recommendations of the 1971 Committee were made; and second, to examine some of those recommendations in the light of new work done since 1971. No attempt has been made to revise or adjust the figures proposed by earlier committees.

The recommendations on energy and protein requirements made by successive committees are shown in Tables 1 and 2. The 1971 Committee made only minor changes in the earlier estimates of energy (*3*, *4*) required by children, but it reduced the estimates for older adolescents and adults. The energy allowance for pregnancy was doubled to 335 MJ (80 000 $kcal_{th}$), which represents the total energy cost of a pregnancy, because it was recognized that, although some women reduce their physical activity during pregnancy, many do not and it was considered that "... a safe level of energy intake is a basic requirement to ensure satisfactory nutrition for the fetus . . . ". On the other hand, the energy allowance for lactation was reduced in the light of evidence that the efficiency of milk production may be greater than had previously been thought. There is little new evidence that would make it possible to re-examine the basis for estimates of energy requirements, and there exists an urgent need for an improved definition of what constitutes an adequate intake of energy.

This Memorandum is concerned mainly with requirements for protein. The 1971 Committee proposed a small increase over that recommended in 1965 (*5*) in the " practical allowance " or " safe intake " of protein for infants and children up to 3 years of age. There seems to be general acceptance of these estimates as appropriate for healthy children. However, it has always been recognized that they

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Table 1. Energy requirements recommended by successive FAO/WHO Expert Committees

Age group (years)	Body weight[a] (kg)	1950 Committee (3)		1957 Committee (4)		1971 Committee (1)	
		$kcal_{th}$ /day	$kcal_{th}$ /kg body weight[b]	$kcal_{th}$ /day	$kcal_{th}$ /kg body weight	$kcal_{th}$ /day	$kcal_{th}$ /kg body weight
Children							
<1	7.3	803	110	803	110	820	112
1–3	13.4	1200	90	1300	97	1360	102
4–6	20.2	1600	79	1700	84	1830	91
7–9	28.1	2000	71	2100	75	2190	78
Male adolescents							
10–12	36.9	2500	68	2500	68	2600	71
13–15	51.3	3200	62	3100	60	2900	57
16–19	62.9	3800	60	3600	57	3070	49
Female adolescents							
10–12	38.0	2500	66	2500	66	2350	62
13–15	49.9	2600	52	2600	52	2490	50
16–19	54.4	2400	44	2400	44	2310	43
Adult men	65.0	3200	49	3200	49	3000	46
Adult women	55.0	2300	42	2300	42	2200	40
Pregnancy		+ 405 (3rd trimester)		40 000 per pregnancy		+ 150 (1st trimester) + 350 (2nd & 3rd trimesters)	
Lactation		+ 1000		+ 1000		+ 550	

Note: 1 $kcal_{th}$ = 4.184 kJ.

[a] From the report of the 1971 Committee (1).

[b] Determined on the basis of body weights given in the report of the 1971 Committee (1).

were unlikely to be adequate for children exposed to repeated infection, as is the case in many developing countries. This problem is considered in more detail below.

The major change made in the 1973 report was a reduction in the estimates of safe protein intake for older children, adolescents, and adults. Since then, several studies on adult men have suggested that the 1973 figures for the reference egg protein may be too low. Some progress has been made in defining requirements of the elderly and of pregnant women, but there is no new information on other age and sex groups. In general, there seems to be a dearth of direct data on the protein and energy requirements for adult women, adolescents, and older children and there is little information on energy–protein interactions in the marginal range of intakes. At the end of this Memorandum, a number of areas in which further work is badly needed are identified.

Most of the discussion since the 1973 report was published has centred around requirements for protein. In examining these matters, this Memorandum has not gone outside the framework of the original report, in which nitrogen balance was used as the main criterion of protein needs. It is recognized that results obtained under the conditions of metabolic balance studies will not necessarily reflect actual requirements and that nitrogen balance may not be an adequate index of optimal nutrition. Assessment of requirements by functional criteria will depend, in the last analysis, on long-term studies in the community. In the meantime, the aim must be the more modest one of trying to determine the physiological limits below which intakes should not fall.

Table 2. Protein requirements (g/kg body weight per day) as recommended by the League of Nations and successive FAO/WHO expert groups

Age group	1936 League of Nations allowance of total protein (from a variety of sources)	Reference protein [a]		Egg or milk protein	
		1955 Committee (*6*): safe practical allowance	1963 Committee (*5*): practical allowance	1971 Committee (*1*): safe level of intake	
6–9 months	—	2.10 [b]	1.50 [f]	1.62	
9–12 months	—	—	1.20 [f]	1.44	
1 year 2 years 3 years	3.50	1.65 [c]	1.06	1.19 [h]	
4 years	3.00	1.20 [d]	0.97	1.02	
7–9 years	2.50	1.05 [e]	0.92	0.88 [h]	
				males	*females*
10–12 years		1.11	0.86	0.80 [h]	0.77 [h]
13–15 years	2.50	1.02	0.84	0.72 [h]	0.63 [h]
16–19 years	1.50	0.69	0.77	0.63 [gh]	0.58 [gh]
Adults	1.00	0.53	0.71	0.57 [h]	0.52 [h]

[a] Reference protein is defined as a protein that is completely utilized for anabolic purposes.
[b] 9 months.
[c] 2 years.
[d] 5 years.
[e] 9 years.
[f] Requirements in terms of either breast milk or cow's milk protein.
[g] 16–17 years.
[h] Average calculated from the value for each year in the age group considered.

THE SAFE LEVEL OF PROTEIN INTAKE

The method adopted by the 1971 Committee has not always been clearly understood. It may be useful to retrace the steps of the Committee's argument and to fill in some gaps where the basis on which estimates were determined is not entirely clear.

Obligatory losses of nitrogen

Direct measurements on young adult males showed that the sum of obligatory losses by all routes was approximately 54 mg of nitrogen per kg of body weight. This figure was derived from the literature and from three studies available to the Committee, which had not been published at that time (*7*, *8*, *9*). In order to extrapolate these data to other age and sex groups for which direct results were not available the Committee, following the example of its predecessor (*5*), made use of the general relationship that has been observed between obligatory nitrogen loss and basal metabolic rate (BMR). For adult women, the estimate of obligatory loss was reduced by about 10% to 49 mg/kg of body weight on the basis of the known sex difference in the BMR of adults.

The BMR of adult males is 105–113 kJ (25–27 $kcal_{th}$) per kg per day, so that the obligatory loss can be taken as approximately 0.48 mg N/basal kJ. The Committee used this value to estimate the obligatory losses in children and adolescents from the figures for BMR given in Annex 4 of the 1973 report. These figures relate to persons of reference weight for age and height up to the age of 18 years. They are not valid for estimating the BMR in adults.

The 1971 Committee recommended that, after the BMR had been determined for any age/sex group, further adjustments within the group should be related to body weight. The special case of undernourished persons with very low body weights is discussed below.

Since 1971, a few additional studies have been published of obligatory losses in young men and elderly men and women. There is no further information about losses in children and adolescents. The results of these studies are summarized in Table 3.

The agreement between the values for urinary loss

Table 3. Obligatory nitrogen losses

Country or area	Reference	No. of subjects	Body weight (kg)	BMR (kJ/kg)	Excretion (mg N/kg)			Total (mg N/ basal kJ)
					urine	faeces	total [a]	
Men aged 20–37 years								
USA	*7*	13	71	109	38	14	57	0.52
USA	*8*	83	73.5	88	37	9	51	0.58
Taiwan	*13*	50	55	109	33	13	51	0.47
India	*32*	4	46	113	38	23	66	0.58
Nigeria	*9*	9	54	109	34	23	62	0.57
Elderly persons								
USA (men)	[b]	6	83 [c]	79	27	10	42	0.53
USA (women)	*54*	11	63.5	71	24	10	39	0.55
USA (men)	*55*	8	71.6	92	34	12	51	0.55

[a] After the addition of 5 mg N/kg for skin and miscellaneous losses. This value may be higher than is warranted for elderly persons and lower than for children.

[b] Zanni, E. et al., unpublished data, 1978.

[c] Body weights were 8–19 kg above the expected weight for height.

per kg of body weight is remarkable, particularly when one considers the difficulty in defining the exact period of time needed for the urinary loss to reach a stable level. The duration of the study will probably have less effect on the faecal loss, yet it is the faecal loss that is more variable. It was higher in Indians and Nigerians, presumably because of the nature of their diet. In four out of the five studies, the total nitrogen loss was somewhat greater than the figure of 0.48 mg N/basal kJ adopted by the 1971 Committee, but the BMR in study 2 (Table 3) was exceptionally low. The weighted mean for all five studies is 0.53 mg N/basal kJ. The agreement between young and old adults is surprisingly good. This suggests that the BMR is indeed an appropriate base for extrapolating estimates of nitrogen loss to different age and sex groups.

From evidence available to the 1971 Committee, it was apparent that urinary and faecal losses in infants and young children may be significantly less than 0.48 mg N/basal kJ (*10*). Therefore, until direct data become available, the continued use of this factor will probably provide a margin of safety for children.

The precise relationship between nitrogen loss and BMR should be re-examined by any future committee. It may be noted that, since in adult men the nitrogen loss per kg of body weight was determined directly, any adjustment of the figure for nitrogen loss per basal kJ would not affect estimates of adult protein requirements. However, it could affect estimates of the protein needs of other age/sex groups extrapolated from the adult data. For this reason, it seems more urgent to obtain direct information on the nitrogen losses of these groups and to avoid as far as possible the necessity for extrapolation, rather than to concentrate on adjustments to the estimate of nitrogen loss per basal kJ.

The subject of nitrogen loss from the skin has aroused some discussion. The figures in the last two columns of Table 3 include an allowance for losses by the skin and other minor routes. The 1971 Committee adopted a value of 5 mg N per kg per day, based mainly on data provided by the Berkeley group (*11*) on subjects consuming little or no dietary protein. It has been suggested that this figure seriously underestimates nitrogen losses that may occur through increased sweating in hot climates. The Committee considered this source of error, but concluded that it is of little significance. Skin losses may be slightly greater in the tropics, amounting to about 10 mg per kg per day for subjects consuming habitual diets, or about 6 mg per kg with a low-protein diet (*12*). Results obtained by Huang (*13*) in Taiwan indicated that the increased skin loss was compensated for by a reduction in urinary nitrogen loss. Ashworth & Harrower (*14*), in a study in Jamaica, demonstrated a small compensation of this kind, and pointed out that the nitrogen concentration in sweat was very low in their subjects, who habitually lived in hot climates. Consolazio et al. (*15*) obtained extremely high rates of nitrogen loss in sweat, with no urinary compensation, in young men on high-protein diets engaged in moderately severe exercise, but their estimates were based on sweat collected in arm bags, which cannot be regarded as representative. Howat et al. (*16*) in a study of pre-adolescent girls showed, as have others (*11*), that the nitrogen loss in sweat is higher at higher protein intakes. At an intake of 1.24 g of mixed protein per kg, the girls' rate of nitrogen loss in sweat was 8 mg/kg. This value is greater, per unit of body weight, than that of sedentary men given 75 g of protein per day and may reflect both a higher level of activity in the children and their proportionately larger surface area. Men lose 0.07 mg of dermal nitrogen per m^2 of body surface per minute per kJ of energy expended on work (*11*). If the rates based on surface area were comparable in children and adults, the loss per kg of body weight would naturally be higher in the children and a comment to this effect was made in the 1973 report. However, it is not always appreciated that, since the BMR per kg is higher in children, a higher dermal nitrogen loss per kg does not imply a higher loss per kJ.

In countries where the normal diet has a high residue, faecal losses may be greater than in developed countries, as shown in Table 3, studies 4 and 5. If account is also taken of the slightly greater skin losses, it might be reasonable to estimate the total obligatory loss as 0.6 mg N/basal kJ under the conditions found in developing countries. However, evidence from studies in Nigeria (*9*) suggests that the increase in obligatory losses may be counterbalanced by an increase in the efficiency of utilization of dietary protein.

The protein requirement for growth and pregnancy

The nitrogen requirement of infants and children, computed by the factorial method, is the sum of the obligatory loss and the nitrogen retained for growth. In the case of young children, a complication arises because the nitrogen concentration of the body increases with age, and there are quite large variations in the estimates of nitrogen concentration given by different authors (*1*). The values in Table 12 of the 1973 report for the growth increment between 6 and 12 months were calculated as the mean nitrogen concentration (derived mainly from the estimates of Fomon, *17*) multiplied by the daily weight increment. It would be more accurate to calculate the total increment in body nitrogen over the age interval, divided by the number of days. However, the difference in result given by the two methods is not important compared with the variability in the estimates of body nitrogen content on which the calculations are based.

In estimating the protein requirement for pregnancy, the 1971 Committee used the figures for nitrogen accretion published by Hytten & Leitch (*18*); these were 80, 400, 740, and 860 mg N/day in the successive quarters of gestation. A subsequent review of all published balances (*19*) has shown the average nitrogen retention during pregnancy to be 1.57 g/day and only slightly less (1.3 g/day) in the first half than in the second. Average balances of about 1.6 g N/day over the latter half of pregnancy have been confirmed in studies of healthy pregnant women consuming their habitual diets (*20*). If these observed values are accepted, the safe intake of milk or egg protein would be increased above the maintenance level by 14 and 16 g/day in the first and second halves of gestation, respectively.

There are no recent data on energy requirements during pregnancy and lactation, or on the protein requirements for lactation. These are subjects that deserve high priority. There is evidence that undernourished women secrete a smaller volume of milk (*21*), and studies in Guatemala have shown that supplements of energy during the second half of pregnancy improve performance during pregnancy and lactation (*22*).

Adjustment for efficiency of utilization of reference protein

The 1971 Committee was the first to consider the important question of whether the obligatory nitrogen loss gives a valid prediction of the amount of dietary protein needed to meet the minimum physiological requirement. Minimal protein needs had previously been expressed (*5*) in terms of a hypothetical reference protein that could be used with 100% efficiency; that is, when fed at the level of the obligatory nitrogen excretion there would be no increase in the urinary and faecal nitrogen losses over and above those found with a protein-free diet. An ideal amino acid pattern was proposed for the hypothetical reference protein, which would provide a standard for determining the quality or score of other proteins. Egg protein might be regarded as the natural protein that most closely resembles the hypothetical reference protein, because egg proteins have a net protein utilization (NPU) of 95–98 in conventional rat assays.

The 1971 Committee examined the results of balance studies in which egg and milk proteins had been fed to infants, children, and adults at levels below or close to the requirement, which is defined as the amount needed to achieve nitrogen equilibrium in adults and adequate retention in children. It was evident that even these high-quality proteins were not utilized with the efficiency that had been assumed. To meet the minimum requirement, the dietary intake had to be 25–50% above that expected from the obligatory losses plus growth increment. It was proposed that the average requirement for egg or milk protein should be taken as 30% greater than that given by the factorial method. Re-examination of the data suggests that the addition should be of the order of 45%. For adults, the ratio of the average daily requirement for balance (77 mg N/kg) to the average obligatory loss (54 mg N/kg) is 1.43. However, it is not considered that the underestimate in the 1973 report is of practical significance, since for adults on a mixed diet the correction for protein quality provides a large margin of safety. The data in Tables 12 and 16 of the 1973 report suggest that in children also the factorial estimates should be increased by 40–50%. However, not much confidence can be attached to this calculation, since none of the balance studies give *minimum* requirements for normal growth. In infants, the factorial estimate plus 30% is in reasonable agreement with the observed intakes of infants fed breast milk (1973 report, Table 23).

No new information has emerged since 1971 on the utilization of egg or milk protein by children, but there have been several studies on adult men. A group from Massachusetts Institute of Technology (MIT) have reported that young men fed formula diets providing the safe level of protein (0.57 g/kg per day) as whole egg powder do not consistently maintain nitrogen balance at habitual levels of energy intake and that some subjects show loss of lean body mass, as shown by diminished whole-body potassium content and decreased urinary creatinine output, together with elevated serum transaminase levels (*23*). These findings are taken as evidence that the dietary protein intake is inadequate over the long term (50–89 days). As there was no group of subjects fed a control diet over the same time span, the extent to which these changes might have been due to other treatment variables (adequacy of minerals and vitamins, nature of the diet, environmental factors) cannot be known. However, investigators at the University of California at Berkeley have not found significant decreases in lean body mass over periods of 15–60 days of feeding the safe level of protein as dried egg white (*24*, *25*). It is important to note that in these studies, care was taken to maintain physical activity and energy intake. These workers observed a fall in urinary creatinine associated with a reduced creatine pool size, which was ascribed to the elimination of creatine from the diet (*26*, *27*). They also found transient elevation of serum transaminase levels with a variety of diets, in many of which the protein intake was above the requirement.

Nicol & Phillips (*9*) fed egg protein at 0.45 g/kg per day to Nigerian men who had previously been accustomed to a moderately low-protein diet. All subjects were in nitrogen balance, even if 10 mg N/kg per day is allowed for skin losses. The results suggest that in these men absorbed nitrogen is more efficiently utilized than in subjects such as those in the USA who are accustomed to high protein intakes.

Interpretation of nitrogen balance

A number of studies since 1971 have shown that the sign and magnitude of nitrogen balance is strongly affected by energy intake when the diet provides the safe level of protein from dried egg white (*24*), dried whole egg (*28*, *29*) or fluid low-fat milk (*30*). In the Berkeley studies (*24*, *30*), subjects confined to the laboratory and given programmed work were barely in nitrogen balance with energy intakes of about 167 kJ (40 $kcal_{th}$)/kg and were clearly in positive balance when the intake was 192 kJ (46 $kcal_{th}$)/kg. In free-living students at MIT, balance was achieved at slightly higher energy intakes of 188–209 kJ (45–50 $kcal_{th}$)/kg. Inoue et al. (*31*) in Japan found that with egg or rice as the source of protein, the nitrogen requirement for balance fell by about 25% when the energy intake was increased from 188 to 238 kJ/kg (from 45 to 57 $kcal_{th}$/kg). Similar results have been reported from India (*32*). It is clear therefore that, in confirmation of earlier studies (*33*, *34*), there is an association between nitrogen balance and energy intake with a variety of protein sources and over a range of intakes of energy and nitrogen.

The magnitude of the effect on nitrogen balance varies from 0.17 to 0.62 mg N retained for each additional kilojoule, with most values between 0.29 and 0.33 mg when intakes are in the maintenance range. In the worst case, if dietary protein is being used at the low efficiency of 20%, as determined by Hegsted (*35*) from an evaluation of short-term balance studies with nitrogen intakes at or above requirement, the increment or decrement in nitrogen balance due to a change in intake of 4.2 kJ (1 $kcal_{th}$)/kg would be equivalent to a change of 6–7 mg of dietary nitrogen or 0.04 g of protein per kg.

In studies where protein is the intentional dietary variable, there has been a general tendency to ensure that energy needs are met by adjusting nonprotein energy intake so that body weight is maintained constant or is slightly increased. Large increases in weight were allowed in early studies, where intakes of over 209 kJ (50 $kcal_{th}$)/kg were not unusual. In view of the relationships described above, this practice would have led to a more positive nitrogen balance and probably to underestimates of the protein requirement. In the more recent studies on which the 1971 Committee based its judgment, weight changes were smaller but generally in the direction of gain, even when the subjects were in negative nitrogen balance and should, in theory, have been losing some lean body mass. On the other hand, both the MIT and California studies (*23*, *24*, *28*, *30*) included subjects whose weight was unchanged, or even declined, when energy intake was raised and nitrogen balance was thereby improved. None of the studies reviewed by the 1971 Committee, nor any of those published since, provide an independent measure of energy requirement. It seems that nitrogen balance is more responsive to small changes in energy intake than is body weight (*30*).

It has not been possible to obtain independent proof of maintenance of body composition under short-term conditions because the precision with which composition can be estimated *in vivo* is well below the degree of change that the balances would predict. Physical work is a further complication, since changes in muscle mass induced by training or inactivity affect both energy balance and the anabolism of protein. Thus an improved understanding of the significance of different energy intakes in relation to protein requirements depends on the development of independent criteria of the state of energy balance.

The nitrogen balance technique has been criticized because increasingly positive nitrogen balances have been observed when nitrogen intake is increased above the presumed level of requirement (*35*). Most of the studies that provide this information have been relatively short-term, but positive balance has been sustained over quite long periods as well (50–200 days, *27*, *36*). It has been generally believed that the phenomenon of sustained positive balance is due to a summation of experimental errors (incomplete ingestion of diet, plate waste, incomplete collection of faeces and urine, neglect of sweat and miscellaneous nitrogen losses, etc.) and that the positive balance is, in fact, a measure of the error term. With better management and equipment, these sources of error should be reduced or eliminated and the true balance state should comprise a series of equally distributed positive and negative daily balances. Some investigators have achieved this precision but usually an arbitrary figure is allowed for unmeasured losses. The 1971 Committee took this amount to be 5 mg N/kg of body weight, including nitrogen lost in sweat, hair, etc. The apparent balance should therefore vary around a stable figure for an adult man of +300–350 mg N/day if only dietary, faecal, and urinary nitrogen are known. Anything above this figure should be reflected in a change in lean body mass. Balances commonly reported of +1000–1500 mg N/day would imply increases of the order of 30 g or more of lean tissue per day and are inconsistent with present concepts of body composition.

It has been suggested that there may be evolution of gaseous nitrogen and that this might vary with nitrogen intake (*37*), but there is no known pathway of gaseous nitrogen formation and the hypothesis has not been confirmed experimentally. It is possible that there is some systematic error in the analytical techniques used for determining nitrogen (usually a Kjeldahl method), but none has been demonstrated. Hegsted (*35*) concluded that " There appears to be no way to select satisfactory [balance] data . . . nor any certain means to improve the quality of the data obtained. There is an obvious need for . . . alternative techniques for estimating nutritional requirements."

In the absence of more effective methods of assessing protein requirements, present estimates of the amount of dietary protein needed to establish nitrogen balance in the adult or nitrogen retention and growth in the child must be accepted as reasonable measures of physiological needs. As suggested in 1971 (*1*), " . . . these estimates provide an indication of how far the protein intake of an individual may fall before there is a significant risk that he may not meet his physiological requirement." As was emphasized at that time, there is no implication that existing protein intakes should be lowered to the suggested safe levels.

Allowance for individual variability

In the 1973 report, it was recommended that average requirements for protein should be increased by 30% to allow for individual variation. For reasons explained in the report, no such allowance was provided in the estimates of energy requirements. It was considered, from the evidence available at that time, that a reasonable estimate of the coefficient of variation of protein requirements among individuals would be 15%. This estimate was based on a number of biological parameters, such as obligatory urinary N output, basal metabolic rate, birth weight, and growth rate, which show a similar degree of variation. It was considered that a coefficient of variation of 15% would make adequate provision for individual variability in subjects undergoing the usual stresses of daily life and that an addition of 30% should cover the needs of the great majority of individuals. The requirement adjusted in this way was denoted the " safe level of intake ".

Since then, Rand et al. (*38*) have proposed that in studies of nitrogen requirement the " safe level of intake " should be derived by a method that includes estimates of confidence limits. The example given by these authors shows that this would have the effect of increasing the allowance for individual variability, at least when the number of subjects is small, as it usually is in nitrogen balance studies. The apparent variability found in individual studies ranges from less than 10% to 30% or more. It is clear that the larger the sample, the more realistic the estimate of variability.

Sukhatme (*39*, *40*) has objected to the use of a figure that includes both inter- and intra-individual variation. He re-examined data on urinary nitrogen excretion obtained by the Berkeley group on subjects fed adequate protein intakes and showed that there are time-related correlations in the day-to-day variations of successive measurements in the same subject. This leads to an estimate of inter-individual variation of 6–7%, which is much less than that given by conventional statistical analysis.

On the other hand, de Ramos & Beaton (unpublished data) were unable to find evidence of serial correlations in the data of Young & Scrimshaw (*56*) from subjects maintained on low-protein diets. The inter-individual variation in urinary nitrogen excretion per kg of body weight was 10–14%, depending on the diet. Intra-individual variation was marginally greater: the total coefficient of variation was 15–22%. The MIT group reported (Rand, W. M. et al., unpublished data) that examination of a long series of measurements of basal urinary nitrogen excretion also fails to reveal evidence of serial correlation. Thus Sukhatme's results from subjects on normal protein intakes are not substantiated when subjects are fed low-protein or protein-free diets.[a] However, his interesting proposal needs to be investigated in more detail.

While it is important to recognize the significance of the observations of Sukhatme and Rand, there is not enough evidence at present to support a change in the estimate of inter-individual variability proposed in 1973.

It is important to note that nobody has actually examined the intra-individual variance of *requirement*. This would involve serial measurements of nitrogen requirement in the same subjects. What has actually been calculated is the variance in nitrogen excretion.

If time-serial correlations do exist, it suggests that there is a process of dynamic regulation, so that requirements within an individual constantly adapt in some degree to the level of previous intake. It is possible that such a process might lead to long-term adaptations, without risk to health, in people accustomed to low protein intakes. The implication is that current estimates of protein requirements, based on short-term nitrogen balances on subjects used to high protein intakes, may have limited value.

Adjustment for protein quality

In the current literature there is still some confusion about the procedures recommended in the 1973 report for correcting for protein quality. It was stated clearly that the results of any bioassay procedure in rat or man must be related to the values for egg or milk measured under the same assay conditions. Omission of this step may give very misleading results.

[a] Recently Sukhatme & Margen (*American journal of clinical nutrition*, **31**: 1237, 1978) reported detailed statistical analyses of a series of consecutive nitrogen balances on individuals. These revealed serial correlations suggesting autoregulation of nitrogen balance. The results also suggest that the regulatory mechanism does not operate at very high or very low levels of nitrogen intake.

There seems to be some misunderstanding that the 1973 report, in using the term NPU, was specifically recommending a particular assay procedure. In fact, the term was intended to be used in a generic sense to indicate a measure of protein value that included both digestibility and efficiency of utilization of absorbed nitrogen. Other methods of assay were mentioned in the 1975 report (*2*), again with the caution that the results should be related to those obtained with egg or milk under the same conditions. In these assays, the intakes of energy and protein should be at or near maintenance levels.

As an alternative to bioassay, a new amino acid scoring pattern was developed, based on estimates of the essential amino acid and total protein requirements of preschool children. It was recognized that this pattern would underestimate the quality and overestimate the requirements of mixed proteins for older children and adults. However, it was considered essential that the correction for protein quality should be valid for young children. This, in effect, provides an added margin of safety for the adult. The amino acid pattern was not intended to be applied to young infants, for whom breast feeding is recommended. The 1971 Committee neglected to offer guidance on correction of the amino acid score for the digestibility of dietary proteins; this oversight was corrected by the informal gathering of experts in 1975. It is now recommended that the amino acid score be adjusted to 85% digestibility if the diet is based on coarse, whole-grained cereals and vegetables and to 90% digestibility in the case of more refined diets. The estimation of dietary protein need would be either:

$$(a)\ \text{Safe level of egg/milk protein} \times \frac{100}{\text{amino acid score}} \times \frac{100}{\text{digestibility}}$$

or

$$(b)\ \text{Safe level of egg/milk protein} \times \frac{100}{\begin{array}{c}\text{bioassayed net utilization}\\ \text{relative to egg/milk}\end{array}}$$

The most significant change in the amino acid scoring pattern was a reduction in the proportion of sulfur-containing amino acids. The result of this was an improvement in the score of many protein sources and mixed diets which, on the basis of rat assays, have been regarded as deficient in these amino acids. The requirements of preschool children (Arroyave, G., unpublished data) and of young men (*41*) for methionine plus cystine have since been reconfirmed. Some reservations have been expressed about the adequacy of lysine in the scoring pattern (Young, V. R., personal communication) but the pattern has proved generally useful for mixed diets.

Not many assays of mixed human diets have been reported since 1973. It seems that, in general, the proposed methods of adjusting for protein quality have been found to be satisfactory. As noted in the 1973 report, Inoue et al. (*31*) found that with an energy intake of 238 kJ (57 $kcal_{th}$)/kg the average daily nitrogen intake needed to secure balance was 76 mg/kg for egg and 96 mg/kg for rice and vegetables. With an energy intake of 188 kJ (45 $kcal_{th}$)/kg, the amounts of nitrogen needed were 102 and 135 mg/kg, respectively. Thus the value of the rice–vegetable diet, relative to that of egg, was 0.80 at the higher and 0.76 at the lower energy intake. These results indicate that the level of energy intake did not have a significant effect on the relative value of the two diets. Three other groups (*32*, *42*, *43*) have reported that 120 mg N/kg from a mixed rice diet was enough to maintain almost all the subjects tested (adults, mainly men) in approximate nitrogen balance. In Nigerian men, nitrogen balance was achieved, on average, on a rice-based diet providing 72 mg N/kg; the calculated NPU was 0.79 (*44*).

These observations in general confirm the 1973 estimates of safe intakes and the corrections proposed for protein quality. However, more tests are needed of habitual diets, with particular attention being paid to the levels of energy intake.

Protein–energy ratio

The problems connected with the use of protein–energy ratios were discussed in some detail in the 1975 report. It is useful to be able to describe both diets and requirements in this way. However, it must be emphasized again that it is misleading to compare the P/E ratio in the diet with the simple ratio of safe level of protein to average energy requirement. It is necessary to include in the calculation not only the average requirements for protein and energy and their coefficients of variation but also an estimate of the correlation between protein and energy requirement. The statistical problems involved in " matching " intakes to requirements were touched on in the 1975 report and have been considered in detail by Beaton & Swiss (*45*) and others.

A point that emerges from this, and which has not been sufficiently appreciated, is the need to distinguish between P/E ratios that are applied to the assessment of individual diets and those that are applied to average or national diets. The magnitude of the ratio appropriate for each purpose will not be the same (*46*). In the following section, when P/E ratios are calculated they represent the relative requirements of an individual.

THE REQUIREMENTS FOR CATCH-UP GROWTH AND FOR RECOVERY FROM INFECTION

The 1975 report (*2*) considered the calculation of energy requirements for subjects who are underweight. It was proposed that the target weight for adults should be the desirable weight for height and the target weight for children should be the desirable weight for age. Recommendations were made concerning allowances that should be used as a standard of reference for assessing the intakes of undernourished subjects, but no suggestions were made about the amounts of energy or protein needed for them to reach their target weight. In the sections that follow, a preliminary attempt to examine the problem of requirements for catch-up growth has been made. It has been studied in children in hospital (*47*, *48*) but the results have not so far been applied to the situation as it is found in the community.

Another question that has been raised repeatedly is the extent to which recurrent infections increase the requirements for protein and energy. If the effects of infection can be translated into terms of weight deficit, then it should be possible to estimate the requirements for recovery in the same way as those for catch-up.

In any actual situation there will be a very wide range of deficit and of severity and frequency of infection. The recommended approach would be to take one or two examples and to calculate the requirements for catch-up on the basis of the assumptions set out below.

Since the problem is most serious in children, a child weighing 7.5 kg at 1 year of age with a height-age of 7 months has been chosen as the starting point. This might be regarded as typical of the condition of many children of this age in a developing country (*49*).

The calculations are based on three assumptions:

1. The factorial method can be applied to give the sum of the requirements for maintenance and for tissue deposition. In this context, the maintenance requirement for energy includes normal physical activity and is taken to cover all the energy requirement except that for growth.

2. The aim is to deposit tissue of normal composition for a young child, i.e., about 18% protein and 30% fat. This assumption involves a fixed relation of protein to energy in the growth component. It is a matter of observation that children showing catch-up growth on the same diet deposit tissue with different proportions of fat and lean, for reasons that are not entirely clear (*47*). It would be possible to allow for this in the calculations, but for the sake of simplicity a single value for the composition of the tissue gained has been chosen.

3. In accordance with the 1973 report, it is assumed that the " inefficiency factor " of 1.3 applies to growth as well as to maintenance. Therefore, to deposit 0.18 g of protein in 1 g of tissue will require an intake of 0.235 g of protein in terms of milk or egg. The figure of 21 kJ (5 $kcal_{th}$)/g has been taken as the energy cost of depositing tissue with the above composition (*48*). This covers both the energy content of the components stored and the energy costs of synthesis. The figure will, of course, vary with the composition of the tissue gained.

The calculations can be modified to take account of variations in the maintenance requirements of both protein and energy, e.g., for protein, average requirement or average plus 2 SD (safe level). In the case of energy, no reliable figures are available for the SD of the maintenance requirement in young children.[a] However, a child with an average requirement for maintenance plus physical activity, i.e., 418 kJ (100 $kcal_{th}$)/kg/day and another whose requirement is the average minus 2 SD, i.e., 293 kJ (70 $kcal_{th}$)/kg/day, can be taken as examples.

All the calculations are made in terms of weight gain, as no information about the requirements for gain in height is available.

[a] The mean coefficient of variation of energy intakes of infants (from the 1973 report (*1*), Table 15) is 14%.

Table 4. Intakes of protein and energy needed for a child, initially weighing 7.5 kg at 1 year of age, to reach normal weight for age (11.4 kg) in 6 months. Effects of infection and of variations in the maintenance requirements

	Maintenance requirement	Percentage of days infected [a]		
		0	20	50
Protein intake needed (g/kg initial body weight per day) [b]				
Average	0.84	1.81	2.07	3.04
Average + 2 SD	1.11	2.14	2.41	3.35
Energy intake needed (kJ/kg initial body weight per day)				
Average	418	640	653	703
Average−1 SD	356	552	565	619
Average−2 SD	293	460	473	536

[a] Based on data from Rowland et al. (*49*). Mean weight loss is 3 g/kg per day during infection. The average child had gastroenteritis for 14 % of the time (SD ± 17 %). It is assumed that growth can only occur on the days when the child is not infected.

[b] All calculations are in terms of milk protein.

The problem of the requirements for recovery from infection can be approached in the same way. For example, Rowland et al. (*49*) in studies in the Gambia have shown a linear relationship between the number of days that a child is ill and the deficit in weight gain (or degree of weight loss). Over a period of more than a year the children, on average, suffered from gastroenteritis for 14% of the time; it was estimated that on average they lost 3 g/kg of body weight for each day of infection. The requirements for making good this deficit can then be calculated along the lines set out above. Such calculations assume that when the child is not sick its appetite is restored and it is capable of growth. This assumption can only be verified in the field.

Several different types of question can be asked, and for each a simplified exponential expression can be derived. For example, one might ask how long it would take an underweight child to reach normal weight for age if it received the amounts of protein and energy appropriate for a normal child of the same height-age or the same chronological age. In these situations, if the child actually consumes its allowances, the rate of catch-up will be limited by the protein supply.

Another question, which may have more practical relevance, is: what fixed daily amounts of protein and energy are needed to restore normal weight for age in a given period, say 6 months? Table 4 shows answers to this question for a child starting from the same initial point, with or without infection. It is assumed that growth can only occur in the periods when the child is not infected.

Conclusions on the requirements for catch-up, including in this term recovery from infection and periods of anorexia, may be summarized as follows:

1. It is obvious that whatever allowances are chosen, catch-up will occur at different rates depending on the individual child's requirements, the composition of the tissue gained, the frequency and severity of infection, etc. It is therefore impossible to specify allowances that will cover all situations.

2. A more rapid rate of growth involves an increase in the requirement for protein relative to that for energy. In view of the difficulties presented by the concept of P/E ratio, it is not useful to express the results in terms of a desired P/E ratio in the diet. To do this would, in any case, have little meaning because of the wide range of situations that have to be covered.

3. Because of the high energy cost of growth, there is a very substantial increase in the absolute energy requirement.

4. In practice the energy intake, or the food intake, is likely to be the factor that limits catch-up, because of the low energy density [a] of the diets

[a] There is no contradiction in recommending that both the protein concentration and the energy density of feeds should be increased, because the energy density depends not only on the fat content but also on the ratio of solids to water. With feeds made from cereals or starchy roots there is an upper limit to the energy density that can be achieved, because if the water content is too low the feed becomes so viscous that it is inedible. It has been found that the addition of oil, even in small amounts, not only increases the energy density but decreases the viscosity, so that the food becomes easier for a child to eat.

available to the young child, the pattern in which feeds are given, and the frequent lack of appetite.

SUMMARY AND CONCLUSIONS

1. This Memorandum has identified, and has attempted to clarify, a number of uncertainties that underlie the recommendations made in the 1973 report. It has also considered the implications of some of the more recent work on protein requirements, continuing the process of review begun in 1975. The main questions that have been raised relate to the safe level of protein intake for adults. Some studies in the USA have suggested that the levels recommended in the 1973 report may be too low when the protein is fed as whole egg; others have failed to confirm this. The present review of the basis on which the original recommendations were made suggests that the figure for egg protein for adults may be marginally low. However, as has been pointed out, the correction for protein quality overcorrects for the older child and adult, and therefore the suggested safe levels of protein for adults consuming a mixed diet cannot be considered as inadequate. This has been confirmed by feeding trials with mixed protein diets. It should also be recognized that it may not be valid to extrapolate results obtained in the USA to people in developing countries, since the extent and significance of adaptive processes that may occur when habitual protein intakes are lower than those customary in North America is not known. This is a subject on which further research is badly needed.

2. The 1971 Committee's estimates of the energy and protein requirements of infants and young children have, for the most part, not been contested and there is no factual evidence that they are not adequate for healthy children. It has never been claimed that these estimates can be applied without modification to subjects who are exposed to repeated infection. Information is becoming available from field studies of the extent to which multiple infections retard the growth of children under the conditions of real life. If recovery from infection is to be complete, the deficits in growth must be made good. This catch-up growth cannot occur without an increased supply of both protein and energy. It can be calculated from the composition of the new tissue deposited, and from what is known of the energy cost of this deposition, that the increase in protein requirement will be greater than the increase in energy requirement. Nevertheless, in practical situations it is more likely to be the amount that the child can and will consume of the food usually available to him, rather than the concentration of protein in that food, that will limit the extent of catch-up growth. This contrasts with the clinical situation, in which feeds high in both energy and protein can be designed and administered to achieve very high rates of catch-up growth. These conclusions suggest that there is need for more work on methods of increasing the energy density of diets of young children without sacrificing the protein–energy ratios. They also show that it would be erroneous to consider the effects of recurrent infections, anorexia, and periods of catch-up growth on protein requirements without, at the same time, considering their effects on energy needs.

3. There is still very little direct information available on the protein requirement of women of all ages, of adolescents, and of older children. Some progress has been made since 1971 in our knowledge of the requirements of elderly people and of pregnant women. New evidence suggests that the 1971 Committee underestimated the extra protein requirement for pregnancy; this is a subject that should be considered by any future Joint FAO/WHO Expert Committee. There is increasing evidence of the critical importance of adequate energy and protein intakes during pregnancy for reproductive performance, lactation, and the development of the child during the first year of life. In assessing the energy requirement, account must also be taken of changes in physical activity that may occur in pregnancy.

4. Another subject on which more information is needed is the ability of local diets to meet protein needs, with special reference to digestibility as well as to the efficiency of nitrogen utilization. In spite of all the work that has been done, there is still uncertainty about the extent to which amino acid scores and biological assays in rats give realistic estimates of the protein value of human diets (*50*). This is particularly important for young children. Results from developing countries show that high-residue diets cause an increase in faecal nitrogen loss. This problem, which was not considered by the 1971 Committee, requires further investigation. There is some evidence that the increased faecal loss is balanced by enhanced efficiency of nitrogen utilization (*9*, *44*).

5. These gaps in knowledge, to which attention has been called in the previous paragraphs, are all

inside the framework of traditional approaches to the problem of determining protein requirements. It seems increasingly clear that the classical nitrogen balance method, which superseded the factorial method, is approaching the limit of its usefulness. In the first place, the continuing nitrogen retention found in some long-term studies of subjects on an adequate or high protein intake must cast some doubts on the validity of the method. More important is the question, frequently posed but never answered, of whether the maintenance of nitrogen balance under the artificial conditions of a metabolic study is a realistic criterion of the adequacy of protein nutrition under the conditions of real life. Put in another way, the question is whether adaptation to low protein intakes, provided that they are adequate to secure balance and normal growth, involves any disadvantages. This question can only be tackled in field studies aimed at developing functional indicators of nutritional state. Just as the protein requirements for nitrogen balance can only be determined by feeding at different levels, so the requirements for health and successful function can probably only be determined by intervention and supplementary feeding, although the difficulties inherent in altering only one variable are clearly recognized. It may be relevant in this connexion that several studies in which cereal diets were supplemented with the amino acids supposed to be limiting have failed to show any effect on the growth of children (*51–53*).

6. The 1971 Committee was the first to consider energy and protein requirements together. In this report, very little attention has been paid to energy requirements, for the reason that virtually no new information has emerged since 1971, except for further surveys of actual intakes. Although it is possible to obtain a general estimate of energy requirements from the known values of BMR and of the energy costs of different kinds of physical activity, there is no simple way of determining the energy requirement of individuals other than the crude and insensitive method of relating changes in intake to changes in body weight or body composition. Thus in studies of protein requirements, it is impossible to specify a level of energy intake for the subjects that will be neither too great nor too small. In fact, the studies that have been made at different levels of energy intake lead to the conclusion that nitrogen balance is a more sensitive measure of energy requirement than of protein requirement.

7. The usual criterion of energy balance, that constant body weight is maintained, is clearly of little value, since it takes no account of whether there is an adequate level of physical activity nor of whether the body weight is optimal. It seems likely that further work on energy requirements will require field studies with measurements of relationships between intake and performance.

RECOMMENDATIONS

1. FAO and WHO have provided outstanding leadership in stimulating reviews of nutrient requirements. The process of review must continue and it is recommended that plans should be made to reconvene a new Joint Expert Committee on energy and protein requirements. It is impossible to predict with any precision the point of time when enough new information will become available to justify this. However, it is necessary to plan several years ahead, and if account is taken of what has been done sine 1971 and of the volume of work at present in progress in many centres, it seems reasonable to propose that an Expert Committee should meet in 1980 or 1981.

2. In the meantime, FAO, WHO, and Member States, in their consideration of nutritional problems, may continue to use the recommendations on energy requirements and safe levels of protein intake made in the 1973 report, as amplified in 1975, with reasonable assurance that they will be appropriate. However, there is special concern about the protein requirements of pregnancy and these should be re-examined as soon as possible.

3. In view of the many gaps in our knowledge of requirements for energy and protein that have been identified in this and previous reports, opportunities should be sought to encourage and promote further research.

4. It is evident that the report of the informal gathering of experts in 1975 has not achieved adequate recognition, and steps should be taken to remedy this.

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